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DOCTORAL THESIS STATEMENT

Czech Technical University in Prague
Faculty of Electrical Engineering
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Ing. Melvi Ulvan

THE INTEGRATION OF IP MULTIMEDIA SUBSYSTEM IN FEMTOCELL NETWORKS

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Candidate: **Ing. Melvi Ulvan**
Establishment: Faculty of Electrical Engineerinng of the CTU in Prague
Address: Technicka 2, 166 27, Prague 6, Czech Republic.

Supervisor: **Ing. Robert Bestak, Ph.D.**
Department: Department of Telecommunication Engineering
Faculty: Faculty of Electrical Engineering of the CTU in Prague
Address: Technická 2, 166 27, Prague 6, Czech Republic.

Opponents:

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Faculty of Electrical Engineering of the CTU in Prague,
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1. CURRENT SITUATION OF THE STUDIED PROBLEMS

The current 3GPP's active standards, particularly for each wireless access technology, describe the *IP Multimedia Subsystem* (IMS) functionality in normal wireless network coverage such as macrocell and microcell, excluding the femtocell. Some sort of integration of IMS-femtocell and femtocell access point and legacy core network are still challenged and questioned. Configuring the IMS framework in new approach of network architecture such as femtocell and designing the femtocell network to support IMS services is quite demanding. But, the most important is to assure the IMS works in the new network architecture such as femtocell. It is interesting to make an analysis how the IMS core network and femtocell network can be integrated. Performance of an interworking and interoperable system is commonly evaluated by means of the net throughput, especially on delay and other performance metrics.

The IMS operation and femtocell network in telecommunication systems has been concerned in several research works. There are several published papers exposing the femtocells in terms of increasing the network capacity, saving energy, supporting high-speed data rate, and providing benefits from the social and economic side. Authors in reference [1] simulated the deployment of femtocells in residential scenario to study their effects on the service experienced by users connected to a macrocell. They found that no significant impact on the dropped call rate when auto-configuration is deployed in the femtocells. In [2], the authors addressed the reduced cost by deploying macrocell and femtocell users in a shared region of spectrum. They proposed a link quality protection algorithm to progressively reduce the target Signal-to-Interference Noise Ratio (SINR). This two-tier distributed power control algorithm ensured minimal network overhead on femtocells. In addition to energy saving and coverage issues, the authors in. [3] proposed the mobility event based self-optimization and coverage adaptation method for femtocell deployment. As the result, the total number of mobility events caused by femtocells deployment is significantly reduced. Moreover, the femtocell's indoor coverage is improved as well. Other technical and business advantages of femtocell deployment as well as the technology state-of-the-art and its challenges have been overviewed and described in [4]. Generally, those papers discuss benefits and technical issues of femtocell deployment, however very few papers address the integration of femtocells into IMS architecture.

In addition to IMS research and technological development, several works have been addressed, mostly in terms of system performances of session establishment procedure. The works in [5] and [6] provided the SIP-based IMS signalling delay for IMS session establishment procedure. In [5], A. Munir analysed the end-to-end delay where both source node and correspondent node are the combination of 3G/UMTS and WiMAX networks. The signalling delay is analysed separately as transmission, processing and queue delays. However, the paper only shows the delay as a whole. It was not described which delay part that contributed the most significant delay. More comprehensive analysis of session establishment procedure was carried out in [6] where the delay properties in each delay entities were investigated. The structure of session establishment signalling that is based on the standard was presented. The authors also examined which delay among the transmission, processing and queuing delays that contributes the most significant delay in the system.

The optimization of SIP session setup delay for voice over IP (VoIP) service in 3G wireless networks is studied in [7]. The authors evaluated SIP session setup performances with various underlying protocols (*transport control protocol* (TCP), *user datagram protocol* (UDP), *radio link protocols* (RLPs)) as a function of the *frame error rate* (FER). The adaptive retransmission timer is proposed to optimizing the delay. In addition [8], the analysis of SIP-based mobility management in 4G wireless network was carried out. Despite they were not concern on session establishment procedure, but some delay issues, particularly the delay on *radio link protocol* (RLP) and non-RLP have been carried out. The authors also provide some parameters which are worth on our work.

The optimisation of efficient route for femtocell-based all IP networks is carried out in [9]. The authors developed two testbeds for FAP connection scenario i.e., the connection through all-IP network and the connection to IMS through a *Radio Access Network* (RAN). The SIP signalling routes and packet routes of the FAP (in both scenarios) are observed and compared. The end-to-end system delays are also measured and reported. However, the authors do not analysed the mobility functionality, such as the handover procedure in particular, at their test-bed.

The characteristic of advanced 3GPP *Home evolved NodeB* (HeNB) including the description of mobility functionality support and the handover procedure are carried out in [10]. The mobility management issues such as mechanism for searching HeNB in the *Closed Subscriber Group* (CSG), cell reselection and handover decision parameters based on *Received Signal Strength Indicator* (RSSI), service cost, load balancing or UE speed are also described by the authors.

More comprehensive works on handover in the femtocell network are done in [11]-[13]. Authors in [11] focus on the macro-tier to the femto-tier handover mechanisms in the CDMA network. They show that an UE needs to scan the whole femto radio spectrum when switching from macrocell to femtocell which is assessed as a timely expensive operation. To deal with this, the cache scheme for femtocell reselection procedure is proposed. By considering the random walk movement, three user movement models are applied to obtain the UE's movement history. The history reports include the number of FAP that the UE visited. The report contains the most recently visited FAPs that have been stored in the cache. Each FAP data only takes 28 bytes in the cache; therefore there are not too much memory and time consumed to capture the most recently history of visited FAPs. The scheme seems to be effective in the *Open Subscriber Group*

(OSG) femtocell's environment containing plenty of FAPs. However, the proposed scheme is relatively inefficient in the CSG femtocell's environment or in the case of the UE visits just a few numbers of FAPs.

To integrate femtocells into the network, some modifications on existing network and protocol architecture of UMTS based macrocell network is proposed in [12]. The modifications include the enhancement of signal message flow during the handover procedure and the measurement process of signal-to-interference ratio when providing handover between macrocell and femtocell. The frequent and unnecessary handovers are also taken into consideration. The analysis is fulfilled on the concentrator-based and without concentrator-based femtocell network architecture. The obtained results indicate that the use of call admission control mechanism is an effective way to avoid unnecessary triggered handovers.

The updated handover procedure between HeNB and eNodeB (eNB) based on the UE speed and *Quality of Service* (QoS) is proposed in [13]. Three different speeds environments are considered: low (0-15 km/h), medium (15-30 km/h) and high speed (>30 km/h). In addition, the real-time and non-real-time traffics are considered as QoS parameters. The analysis reveals that the proposed algorithm has a better performance than the traditional one from the point of unnecessary triggered handovers. However, the considered speeds seem unrealistic since the HeNB only deals with the very low speed terminals (0-5 km/h).

Authors in [14] use testbed-based experiments to investigate a possible integration of femtocells into WiFi and WiMAX systems. The authors provide comprehensive measurements of vertical handover delay where the vertical handover functionalities are deployed via SIP protocol. It is concluded that the substantial delay is incurred by the DHCP mechanism, the authentication process in WiMAX and the probing process in WiFi. However, there is no a clear description how WiFi and WiMAX systems can be integrated particularly at the MAC layer. To our best knowledge, no works have analyzed the vertical handover in the typical femtocell's handover scenarios such as hand-in, hand-out and inter-FAP.

Furthermore, research and technological development on network entry in macrocell network has been going extensively to provide better *Radio Resource Management* (RRM). However, based on our knowledge, the work on network entry in femtocell is still occasional.

In macrocell network, several research works have been published. In 3GPP-LTE technology, procedure of entering and joining the network is known as LTE attach procedure. So far, none of published research paper related to the LTE attach procedure has found. Some interesting descriptions of LTE attach procedure have been found in some technical white papers.

The close related works is on the LTE-based handover procedure as carried out in [15]. In this works, the network re-entry has been described as part of handover procedure. When a Femto User Equipment (F-UE, the MS terminology for LTE-based femtocell) is moving from the e-NodeB macrocell (eNB - the BS terminology for 3GPP-LTE) and entering the coverage of Home e-NodeB (HeNB – the FAP terminology for 3GPP-LTE), the handover process called *hand-in* is performed. In this case, the HeNB/FAP performs the admission control dependent on the quality of service (QoS) information and prepares handover with layer 1/layer 2 (L1/L2.) signalling.

In addition, the IMS' session establishment procedure in femtocel network has been reviewed in [16].Two different registration procedures are described; the first one is the registration to attach the FUE into the FAP. The second is the session initiation protocol (SIP) registration, where the FUE as the IMS' client registering into the IMS core network. The particular signalling call flows for session establishment procedure is proposed. In addition, the signalling performance is intended to be determined by mean of delay properties. The IMS connection delay, processing delay and queue delay are suggested to be considered as the delay properties of Session Initiation Delay.

Many technical and theoretical methodologies have been presented for obtaining the technical improvement in the IMS system and Femtocell network, in term of SIP signalling procedure, delay performance analysis, and mobility functionality support. Some of the related works overviewed in the previous section can be distinguished as a novel contribution and/or the technical state of the art, which are derived to our purposes in this thesis.

The ability of IMS to converged various network architectures and provide the intelligent interaction of applications and services as described in the standards (e.g. in [17] [18]), provided the basic references for us to integrate IMS with the emerging femtocell network. The performance analysis (e.g., in [5] – [8]) gave the idea in the measurement of session initiation delay in IMS system. We follow the idea for analysed the performance of session establishment delay in the integrated IMS – femtocell network. Nevertheless, we improve the method by distinguishing the analysis separately, i.e. session initiation delay and network entry delay. Thus, our proposed method can be precisely used to determine the part of the system that contributes the most significant delay.

We also adopted the network entry procedure (e.g. in [15] [16]) and improve the entry scheduling algorithm in order to optimising the attach procedure for integrated IMS – femtocell network. The new LTE messages exchange and new IMS signalling flows for the optimised attach procedure has been proposed.

We also proposed a novel mechanism and a new metric based on mobility prediction for handover decision in femtocell network to ensure the quality of service of the system where the large number of possible femto access points (FAPs). The mechanism is combined with the handover strategies (e.g., in [19] [20]) i.e., proactive handover to minimize packet loss and high latency during handover, in addition, the reactive handover strategy is to prevent the very frequent and unnecessary handovers due to the large numbers of FAPs

Finally, the deployment of IMS testbed (e.g., [9]) gave the understanding on how to develop our integrated IMS – femtocell network testbed, and created, running, and measured the simulation processes.

2. AIMS OF THE DOCTORAL THESIS

The aim of thesis is to develop a feasible solution for the Next Generation Wireless Network by integrating the IMS core network within the femtocell environment. The main objectives of the thesis are as follow:

- To determine and analyse IMS functionalities during the session establishment procedure. The session establishment signalling procedure and delay performance of the procedure is examined. Signalling procedure including all IMS' entities from the point of time is analysed.
- To determine the delay during transmission of signal messages and the delay when the SIP messages are in network queues. The transmission delay is analysed as end-to-end delay where the *source terminal* (ST) and the *correspondent terminal* (CT) are in various technologies.
- To enhance the mobility functionality on femtocell network, by analysing the handover mechanism and provide the optimised decision strategy for handover process within a femtocell network.
- To propose an enhanced handover procedure, based on 3GPP LTE technology, to prevent and to mitigate the frequent and unnecessary handovers due to the large number of FAPs.
- To investigate and determine the appropriate IMS-femtocell integration mechanism. In addition, the effective and efficient IMS *Session Initiation Protocol* (SIP) signalling when it works on femtocell environment will be presented. Another critical issue such as the system performance of session establishment signalling of source and correspondent nodes is also taken into account.

3. WORKING METHODS

In technical point of view, the thesis is composed of 3 parts.

Session Establishment Signalling in IMS

The first part of the thesis is focused on the enhancement of SIP signalling mechanism and optimization of SIP signalling procedure on IMS' session establishment process. The structure of session establishment signalling process is enhanced. The performance evaluation methods of session establishment signalling by *Session Initiation Delay* (SID) is introduced and conducted at: IMS' entities (i.e., S-CSCF, P-CSCF, I-CSCF, and HSS); during the transmission of signal messages; and when the SIP messages are in network queues. The evaluation are deployed in several end-to-end wireless link scenarios i.e., UMTS to UMTS, WiMAX to WiMAX, UMTS to WiMAX and vice versa. The comprehensive analysis is done since it included the analysis of processing, transmission, and queuing delays.

The session establishment signalling delay is known as the Session

Initiation Delay (SID) which is defined as the period between the instant the originator of a session triggers the initiate session command and the instant the session initiator receives the message that the other party has been alerted [21]. SID is a user QoS parameter, the ITU specification E.721 defines the average delay for three connection types as local connection (3.0 sec), toll connection (5.0 sec) and international connection (8.0 sec). The standard is worth to be considered as the delay baseline, though the specifications in recent network parameters are much better than the standard suggested. Another standard that is important to be considered is ITU Rec. G.114 which defined network delay for voice application in packet network.

In this thesis, the delay is analysed in three parts of communication link, the transmission delay, the processing delay and the queue delay. Therefore, the end-to-end wireless communication links can be calculated as [5]:

$$D_{total} = D_{transmission} + D_{processing} + D_{queue} \tag{1}$$

In this work we consider four wireless end-to-end links transmission scenarios i.e. UMTS-UMTS, WiMAX-WiMAX, UMTS-WiMAX and WiMAX-UMTS. The transmission delay can be affected by the underlaying protocols used by SIP (e.g. UDP, TCP, RLCs) which influence the session setup time. Another effect may arise from the error recovery strategies (e.g. ARQ, FEC, HARQ) which are not considered in our work.

In wireless transmission, the RLC is used to improve the performance of frame error rate (FER) due to bandwidth availability and channel condition. Since we consider the channel rates (B/W) of 19.2 kbps and 128 kbps for UMTS network, and 4 Mbps and 24 Mbps for WiMAX, therefore the RLC is utilized on UMTS network. WiMAX is assigned as Non-RLC due to the higher bandwidth availability.

The number of frame a packet (k) is required to be calculated for every specified channel rates. In UMTS, the RLC frame duration or also known as inter-frame time (τ) is assumed 20 ms. In addition for WiMAX, the frame duration and inter-frame time is assumed 2.5 ms. Moreover, in WiMAXthe frame duration is independent of the channel bit rate. If 1 byte is equal to 8 bits, then number of bytes in each frame can be calculated as *B/W* x τ x 1/8. Subsequently, the value of ***k*** for particular signalling messages as shown in Table 3.1 can be calculated as:

$$k = \frac{number\ of\ byte}{message\ size} \tag{2}$$

Hence for instance, value of ***k*** for INVITE message at channel rate 19.2 kbps is calculated as follow: Number of byte in each frame is $19.2 \times 10^3 \times 20 \times 10^3 \times 1/8 = 48$ bytes. Value of ***k*** can be obtained as 810/48 = 17.

By using the same method for other SIP messages for the given channel rates, we can determine the value of ***k*** corresponding to different types of messages involved in session establishment as shown at Table 3.1.

Table 3.1 ***k*** value of SIP messages for specified channel rates

Session establishment message	**Channel rate**			
	19.2 kbps	**128 kbps**	**4 Mbps**	**24 Mbps**
INVITE	17	3	1	1
100 TRYING	6	1	1	1
183 SESSION PROGRESS	6	1	1	1
PRACK	6	1	1	1
200 OK	3	1	1	1
UPDATE	6	1	1	1
180 RINGING	6	1	1	1
ACK	2	1	1	1

To analyse the delay for transmitting SIP messages over the UMTS network, we exploit the delay model for frame and packet transmission over a wireless link which is proposed in [22]. The analysis of transport delay when transmitting a packet over the RLC is given as:

$$D_{RLP} = D + (k-1)\tau + \frac{k\left[P_f - (1-p)\right]}{P_f^2} \times \left| \sum_{j=1}^{n} \sum_{i=1}^{j} P(C_{ij}) \left[2jD + \left(\frac{j(j+1)}{2} + i \right) \tau \right] \right| \quad (3)$$

The open-air operation of UMTS radio access network is vulnerable to noise influenced that generate packet loss. In equation 3 above, the effective packet loss is noted by P_f, and can be calculated as follow:

$$P_f = 1 - p + \sum_{j=1}^{n} \sum_{i=1}^{j} P(C_{ij}) = 1 - p\left[p(2-p)\right]^{n(n+1)/2} \quad (4)$$

In case of WiMAX network, there is no RLC retransmission required. However, the retransmission may be done by upper layer protocols until the successful transmission is completed. The upper layer protocol packet loss rate (***q***) in this case is given *as* $q = 1 - (1-p)^2$, where ***p*** is the probability a frame is in error and ***k*** is the number of frames in a packet transmitted. If $\boldsymbol{N_m}$ is noted as the number of such retransmission, then the average delay of transmitting a packet over the WiMAX network ($\boldsymbol{D_{Non\text{-}RLC}}$) is calculated as follow:

$$D_{Non-RLP} = (k-1)\tau + \frac{D}{(1-q^{N_m})(1-2q)} + \frac{1-q}{1-q^{N_m}} \times D\left[\frac{q^{N_m}}{1-q} - \frac{2^{N_m+1} \times q^{N_m}}{1-2q}\right] \quad (5)$$

All parameters involved in equation 3, 4 and 5 are expressed at Table 3.2.

Table 3.2. Parameters, description and values

Symbol	Parameter description	Value
ρ	Utilization	0.7 for HSS 0.4 for other entities
T, τ	Frame Duration or Inter-frame time	20 ms (UMTS) 2.5 ms (WiMAX)
μ	Processing rate for each SIP message	250 packet/s
p	Probability of a frame being in error	0.02 (constant)
D	Propagation delay	100 ms for UMTS 0.27 (4 Mbps) 0.049 (24 Mbps)
k	Number of frame	5 (constant)
n	Maximum number of RLC	3
L	IP address length in bits	32
S	Machine word size in bits	32
N_m	Number of retransmission	2

The session establishment processes in IMS involve 12 message exchanges between the source terminal and P-CSCF of the visited IMS network. In addition, there are also 12 message exchanges which are involved between P-CSCF of the terminating IMS network and correspondent terminal.

At the first scenario, the source and correspondent terminals are in UMTS network, therefore the IMS session establishment transmission delay is given as:

$$D_{trans-UMTS} = 24 messages \times D_{RLC} \tag{6}$$

By using the same approach, we can determine the IMS session establishment transmission delay for the second scenario where both source and correspondent terminals are in WiMAX network. The delay is calculated as:

$$D_{trans-WiMAX} = 24 messages \times D_{Non-RLC} \tag{7}$$

Since the third and fourth scenarios are similar, where the source terminal is in UMTS and the correspondent terminal is in WiMAX and vice versa, thus the session establishment transmission delay is given as:

$$D_{trans-UW/WU} = 12 messages \times D_{RLC} + 12 messages \times D_{Non-RLC} \tag{8}$$

The results are depicted in section 4.

Mobility Functionality in Femtocell Network

The second part or the thesis included the investigation on one of the mobility functionality of femtocell network, i.e., handover procedure. The 3GPP

LTE based handover procedure is considered. Three scenarios are studied: hand-in, hand-out and inter-FAP (see Figure 3.1). The handover procedure and the signalling flows have also been analysed. Since plenty of target FAPs were involved in the hand-in process, it is a challenge to make a selection of the target FAP. The mobility prediction mechanism is proposed to cope with this issue. This scheme can be used to predict the heading position of the UE and then estimate the target FAP to which the UE may be connected. This part also comprised the proposal of E-UTRAN architecture enhancement as well as the modification of communication procedure among EPC, MME, SGW and FGW, in order to have a better procedure when deploying the femtocell into the system.

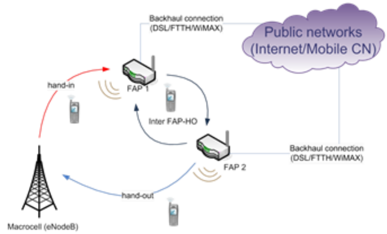

Figure 3.1 Handover scenario in the femtocell-based network.

The LTE-based handover procedure within the femtocell network is intended to minimise the interruption time. It is also designed to be seamless when occurring to/from other technology platforms (e.g., 2G/3G, WiMAX, etc.).

Several network elements take part during the handover process. The *Evolved UMTS Terrestrial Radio Access Network* (E-UTRAN) is the key element since it provides all system functionalities [52]. The E-UTRAN consists of a single eNB or HeNB/FAP that also include *Radio Resource Control* (RRC) layer that manages the handover procedure. The E-UTRAN interacts with the EPC system consisting of *Mobility Management Entity* (MME), *Serving Gateway* (SGW) and *Femto Gateway* (FGW).

The handover from macrocell to femtocell is quite challenging since there are plenty of possible target FAPs. During the hand-in procedure, the UE needs to select the most appropriate target FAP. Generally, the basic condition in the handover decision is the interference level. In this paper, we introduce the mobility prediction as an additional condition in the handover decision mechanism in order to optimise the handover procedure. The signalling message flow of the proposed handover procedure for hand-in scenario is shown in Figure 3.2.

Besides the horizontal handover, the 3GPP standards specify three types of vertical handovers in the LTE systems [55]:

- Inter-RAT handover that refers to the handover between LTE and earlier 3GPP technologies (e.g., UMTS, GPRS/EDGE, GSM).

- Inter-LTE handover that refers to the handover between LTE cells (including the handover between LTE and LTE-A) where the MME and SGW entities are not the same.
- Inter-technology handover that refers to the handover between LTE and non-3GPP technologies (e.g., WiMAX or WiFi).

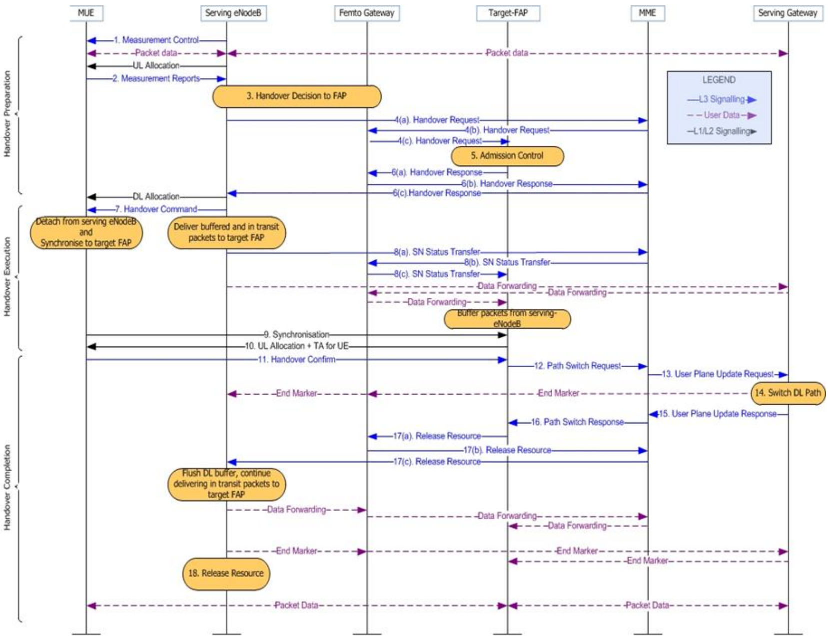

Figure 3.2 Messages flow for hand-in (handover from macrocell to femtocell)

The handover decision of vertical handover can be established in the following ways:

- Network-based handover: the decision to provide a handover is done by network.
- *Macro User Equipment* (MUE)-based handover: the MUE makes the handover decision and informs the network about it. Upon receiving the information, the network makes the final decision based on RRM strategy.

According to the development of LTE standard, a hybrid approach is used to decide the handover in LTE network, where the MUE will assist in the handover decision by measuring signals of the neighbouring cells and reporting the measurements to the network. In turn, the network decides to perform the handover based on handover timing and the target cell. The measured parameters and the use of thresholds are set up by network. Due to limitation space, in this dissertation statement, we present the inter-RAT vertical handover (hand-in), from the LTE-based macrocells to UMTS-based FAP.

In this scenario, the source-MBS (macrocell-eNB) is connected to the source-MME and source-SGW while the target FAP is connected to the target-SGSN and target-SGW. It is assumed that both source and target SGWs are connected to the same PGW (*Packet Data Network* – PDN Gateway).

Based on the standardized handover procedure and our proposed procedure for horizontal handover, we enhanced the procedure for this vertical handover scenario as shown in Figure 3.3.

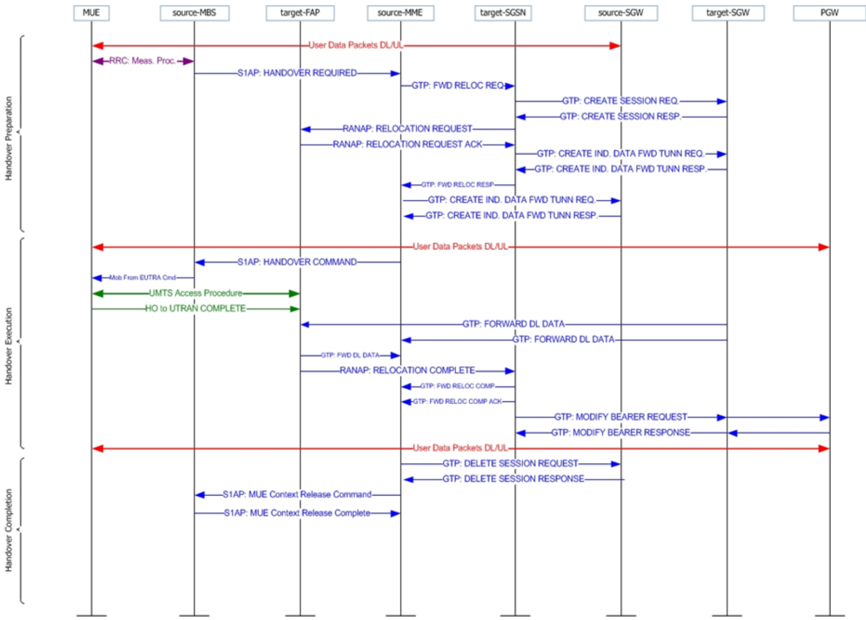

Figure 3.3 Message flow for inter-RAT vertical hand-in (from LTE-based MBS to UMTS-FAP).

In the network controlled handover, the source-MBS decides about the handover by comparing the RSSI that is received from MUE and FAP. However, when deploying CSG femtocells, other parameters such as service cost, load balancing, and UE speed, which might influence the handover decision, should also be considered. From the load balancing point of view when a large number of active UEs are located in a given cell, the available resources may be insufficient to meet the QoS requirements for the real time service but it may offer the sufficient quality for the best effort service.

In this thesis, we suggest the movement prediction mechanism as an additional parameter in the handover decision mechanism. Our analysis of prediction of user's movement reposes on use of Markov process. Let us consider an UE (connecting to the source-MBS) that is randomly moving. Based on Markovian characteristics, the movement may start at any position in its original cell (e.g. at point (x,y)) and the UE can subsequently move to any other cell/position (states) or remain at the current position with certain probability. The transition probability from *state (i)* to state *(j)* is given by the current state only [56]. The mobility prediction can be more precise if the initial probability of UE in a particular state is determined. Additionally, the prediction can be further improved if the initial status other parameters (e.g. the UE speed, distance of target, etc.) are determined as well. These parameters can be represented by initial *distribution matrix* (*p*). More details about the mobility prediction method can be found in [57].

In the similar way as the prediction of user's movement, we analyse macro-femto network. The network consists of twenty one cells (states) scenarios (n = 21); 1 source-MBS (source cell) and 20 FAPs (target-cells). The very frequent and unnecessary handover can be mitigated by deploying the reactive handover. The handover can be postponed until the UE reaches the (predicted) target FAP. The principle of optimisation algorithm can be seen in term of pseudo-code below. For the UE speed, we consider the maximum speed of 10 km/h.

```
1.    INITIALISATION # HO algorithm
2.    EXAMINE RSSI/CINR # either RSSI or CINR
3.    IF RSSI_MBS < RSSI_FAP
          Perform HAND-IN
4.    ELSE
          No HAND-IN
5.    EXAMINE V        # V is the speed of UE
6.    IF V > 10 Km/h
          NO HAND-IN
7.    ELSE IF V>  5 Km/h
          PERFORM MOBILITY PREDICTION
          IF Traffic = Real-Time
                    PERFORM PROACTIVE HO
          ELSE IF Traffic = Non Real-Time
                    PERFORM REACTIVE HO
8.    ELSE IF Traffic =Real-Time
          PERFORM PROACTIVE HO
          IF Traffic = Non Real-Time
                    PERFORM REACTIVE HO
9.    ELSE
          PERFORM NORMAL HO
      RETURN
```

Interworking of IMS and Femtocell Network

The last part of this thesis conducted the deployment of IMS service in femtocell environment. A feasible network integration designs called the SIP/IMS-based integration with all-IP connectivity is proposed as a new design for the technology framework of the 4G wireless technology called the Next Generation Wireless Network (NGWN). The work included the development of a test-bed of the proposed design. The testbed, in fact, composes two main systems i.e., the femtocell system and IMS system. The developed testbed configuration is depicted in Figure 3.4

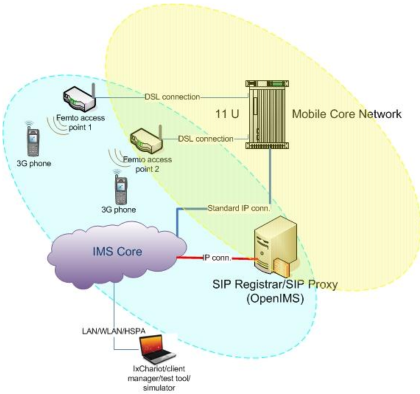

Figure 3.4. Testbed configuration

This advanced 3G-based femtocell system consists of the *Femto User Equipment* (F-UE) which is connected to mobile core network (*Evolved Packet Core* – EPC) through the FAP. The functionality of the *Radio Access Network* (RAN) is integrated into the FAP. The femto gateway (FGW) that provides standard *Iu* interface to integrate the FAP into EPC, responsible for protocol conversion, and creates a virtual RNC interface to the legacy network, is assumed to be located in the mobile operator premises. The FAP, in this testbed, is connected to the mobile core network through a DSL connection.

Furthermore, IMS system is divided into three layers, i.e., connectivity layer, control layer, and service layer [7]. In this testbed, IMS core network is connected to mobile core network by using a standard internet connection. The control layer comprises network control servers for managing call or session set-up, modification and release. The heart of the control layer consists of the *Call Session Control Function* (CSCF) servers, also known as SIP servers. This layer also includes the *home subscriber server* (HSS) database, *subscriber location function* (SLF) database, *policy decision function* (PDF), and *breakout gateway control function* (BGCF). The application layer comprises application and content servers to execute value-added services for the user.

4. SELECTED RESULTS and DISCUSSION

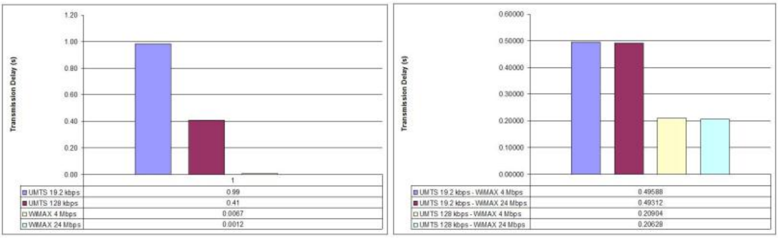

Figure 4.1 Session establishment transmission delay: UMTS-UMTS and WiMAX-WiMAX (left); UMTS-WiMAX (right)

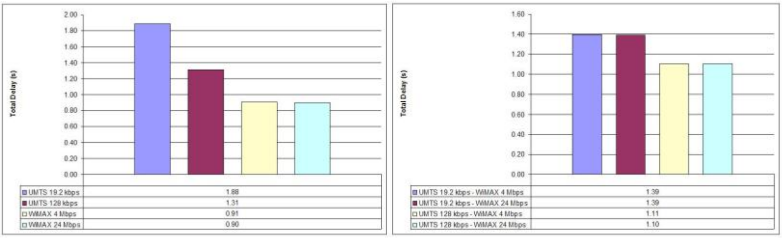

Figure 4.2 Total delay of IMS session establishment procedure: UMTS-UMTS and WiMAX-WiMAX (left); UMTS-WiMAX (right)

The analysis of session establishment delay is initiated by examine the delay in transmission link for the channel rate of 19.2 kbps and 128 kbps in UMTS network and 4 Mbps and 24 Mbps in WiMAX network. Figure 4.1 shows the transmission delay when the source and correspondent terminals are in both UMTS and WiMAX networks separately (left figure) and UMTS – WiMAX (right figure). It can be observed that the session establishment delay is significantly affected by the channel rate, since the delay decrease considerably as the channel rate increase. The WiMAX network with higher channel rates are outperform the UMTS network. Another interesting observation is that the session establishment delay is negligibly affected by altering the WiMAX channel rate. It seems the value of ***k*** is remaining the same in higher channel rate.

The subsequent session establishment delay assessed in term of processing delay and queuing delay. The end-to-end wireless link scenarios have a minor impact on both delays since the delays are influenced by the processes that take place in each network entities such as P-CSCF, S-CSCF, I-CSCF and HSS, including the source and correspondent terminal. The processing and queue delays are much more affected by the IMS service/processing rate, signalling arrival rate and number of subscribers. Figure 4.2 shows the total delay of end-to-end session establishment procedure in all scenarios.

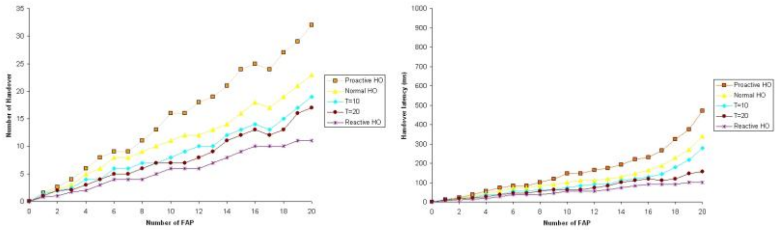

Figure 4.3 Performance of handover: in term of number of handover (left), and in term of handover (right)

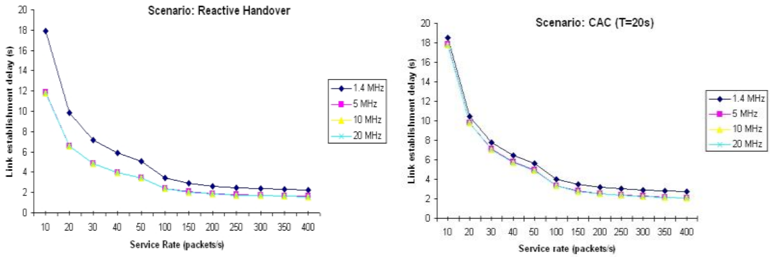

Figure 4.4 Performance comparison of reactive handover mechanism (left) and call admission control mechanism (right)

The depicted results in Figure 4.3 are deal with the speed and traffic constraints as stated in the optimization algorithm. As can be seen, the numbers of handovers increase almost linearly as the number of deployed FAPs increase. Due to the principle to postpone the handover until the moment of losing the current signal, the reactive handover scheme provides the lowest number of handovers compared to other schemes. In addition, the figure at right shows that the reactive handover scheme also provides the lowest handover latency comparing to other decision strategies. It can also be seen that the reactive handover and call admission control (CAC T=20s) have better performance among others strategy. For further performance analysis, these both strategies are taken to be examined in term of link establishment delay.

Furthermore, as can be seen in Figure 4.4, the worst results is provided by the 1.4 MHz channel bandwidth. Obviously, it is due to the lower number of available resource block in low rate channel bandwidth. It can also be observed that for higher channel bandwidth and higher service rate (above 200 packets/s) the reactive handover and CAC (T=20s) provide similar performance. It is due to the large number of available resource blocks. On the other hand, in lower service rates some interval time is required when fulfilling each available resource blocks. Due to its behaviour the CAC scheme waste the time that affects the overall performance of link establishment.

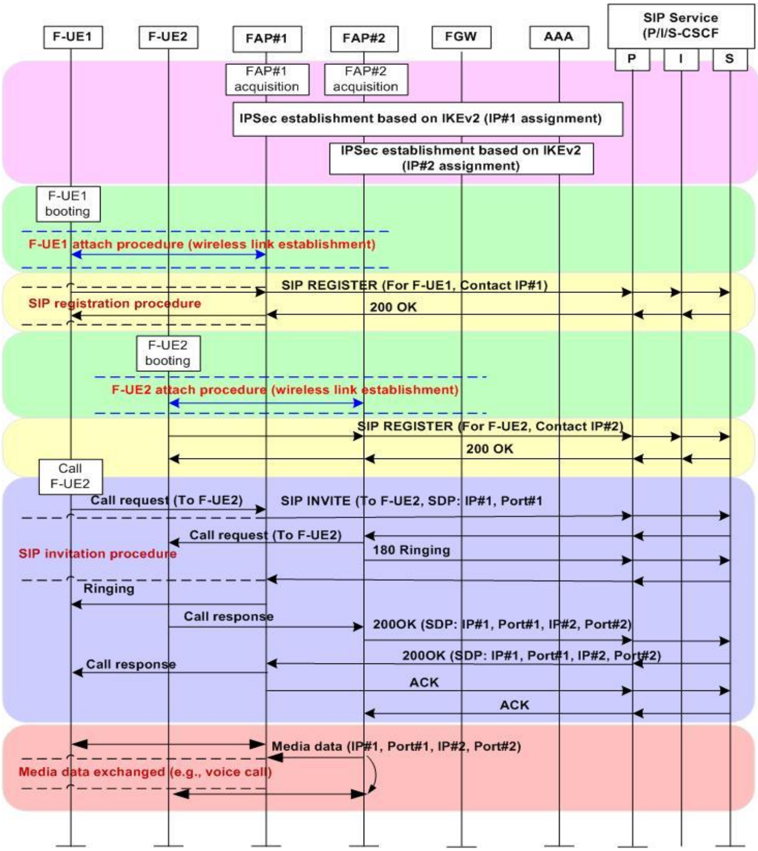

Figure 4.5. Signalling flows of session establishment procedure in integrated LTE-based femtocell and IMS network

In integrated IMS-Femtocell system, there are two individual registration procedures. The first is the attach procedure of F-UE into mobile core network, and followed by the registration of IMS's client at F-UE into IMS core network.

Based on the test case result, there are five stages conduct for the attach procedure and session establishment as follows:

Stage-1: FAP acquisition; the both FAPs are switched on, and then conduct the registration and acquisition procedures.

Stage-2: F-UE attach; Once the procedure in stage-1 completed, the FAP is ready to serve the F-UE.

Stage-3: SIP registration procedure; The registration procedure in IMS starts with the *SIP REGISTER* message request is being sent to the P-CSCF by the UE..

The S-CSCF sends a *200 OK* message to inform the UE of successful registration.

Stage-4: Session establishment procedure; originating F-UE1 generates a SIP INVITE request and sends it to the P-CSCF.

Stage-5: Media transfer; upon completed the session establishment procedure, both F-UE1 and F-UE2 can start the communication using the assigned transfer and communication protocols.

Figure 4.5 shows the detail signaling flows of session establishment process conducted in the testbed. The comprehensive explanation of the LTE attached procedure and the registration process on IMS core network can be found in original thesis.

Example of measurements parameters and results of packet streams in term of traffic, jitter and max delta are depicted consecutively in Figure 4.6 – 4.8. Packet stream analysis conducted in this thesis considers five most common protocols in IMS system, i.e., SIP, HTTP, TCP, UDP and RTP (see Figure 4.6). Although there is no traffic filtering mechanism employed, so that the test-bed system acts like in the real network, the plotted of Figure 4 represents the considered protocols only. As we can see, SIP, UDP and RTP protocols dominated the packet traffic. SIP has the largest number of packets due to its signalling characteristics, i.e., sending the signalling messages for each created sessions. We can also see that from the period 240s to 264s the considerable number of RTP packets increased. It means during that time period the call session is established in the system.

Figure 4.7 and 4.8 shows the performance of call session in RTP packet. All traffic packets were captured in both forward and reverse streams. Forward stream means all traffic packets from IMS' clients F-UE1 to F-UE2, whereas the reverse stream is the traffic packet in opposite direction. Maximum delta, as shown in Figure 4.7 represents the maximum gap between two consecutive packets. According to RFC 3550, the common value of max delta for G.729 codec, which is used in this case, is 20 ms. Therefore, the ideal condition should be close to this value. However, our test-bed system does not have such particular value. The max delta is 60.00 ms at packet no. 2000. Apparently, the packets in our simulated system are not sent at a constant rate. In the real network, the max delta of 220ms on packet is big issue because it causes the voice quality of the stream as heard on the terminals end to deteriorate. Filtering the unessential packets in the network or changing the codec to G.711 might solve the issue.

In addition, jitter is a variation in packet transit delay caused by particular circumstances on the path through the network. It is a smoothed derivative of the inter-arrival delta. So it will not get nearly as high as the deltas itself, unless fluctuation of deltas are very frequent and has high amplitude over a longer period of time. In Table II we can see that the maximum jitter is 3.18 ms with the average jitter of 2.03 ms. Figure 6 shows the characteristic of jitter, in both forward and reverse streams, on the test-bed system during 21 seconds period of measurement time. The jitters in forward stream fluctuated as the effect of queuing, contention or serialisation effects in the network. In contrast, the reverse jitters are considerably constant. It is not due to the better packets streaming from F-UE2 to F-UE1, but the reason is only those received packets have been captured at the captured port. Providing the proper size of jitter buffer might solve the issue.

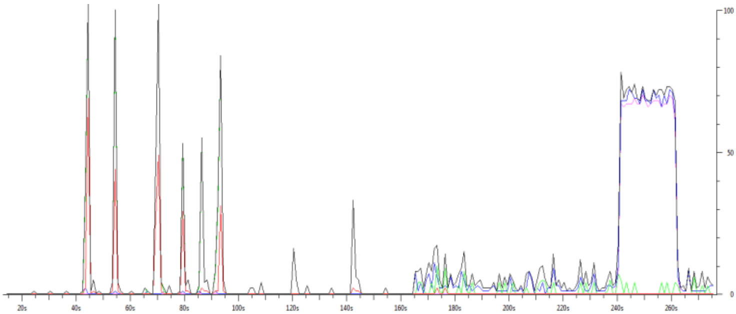

Figure 4.6 Example of traffic characteristic on integrated IMS and Femtocell network (passed through the FAP)

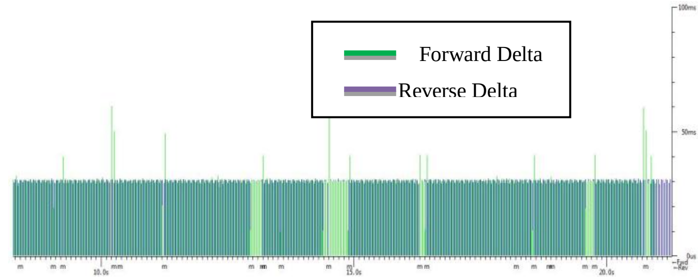

Figure 4.7 Example of max delta; forward stream (F-UE1 to F-UE2), reverse stream (F-UE2 to F-UE1)

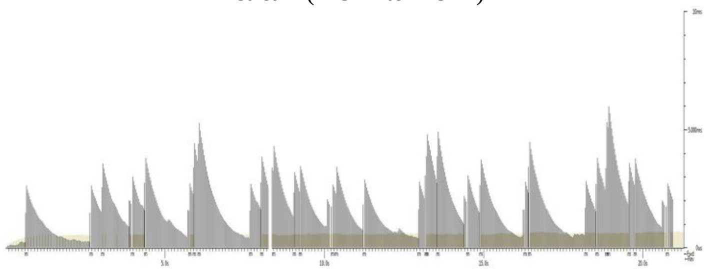

Figure 4.8 Example of jitter charateristic; forward stream(F-UE1 to F-UE2), reverse stream (F-UE2 to F-UE1)

5. CONCLUSION and FUTURE DIRECTION

In this thesis, we have investigated the IMS functionality in term of session establishment process, analysed the mobility functionality on femtocell network, and proposed the integrated architecture of IMS – Femtocell network, as well as examined their performances. Various wireless technologies have been considered, including 3GPP UMTS and LTE, and IEE802.16 WiMAX network.

We have presented the method on analysing the session establishment performance and introduced some approaches to deal with several aspects, by means of theoretical, experimental, and by simulations. In addition, we have presented the new all-IP IMS – Femtocell integration architecture, and proposed movement prediction method in order to optimised one aspect of mobility functionality that is handover.

We started off by considering the physical and logical aspects of IMS entities and SIP messages. The concepts of IMS in providing access to various technologies and services by using common control architecture, regardless of the media type, were works well for all media. Some essential SIP messages which involve in session establishment process were analysed. Moreover, the Session Initiation Delay (SID), which covered the delay in data transmission, IMS' processing delay, and the delay when the messages are in the queue before being processed at the involved entities, is considered as the performance parameters. The SID performances analysis have been deployed in several end-to-end wireless link scenarios where the IMS' source and destination terminals are resided i.e., UMTS to UMTS, WiMAX to WiMAX, UMTS to WiMAX and vice versa. It can be observed that the session establishment delay is significantly affected by the channel data rate, since the delay considerably decreases as the channel rate increases. The WiMAX network scenario with higher channel rates outperforms the UMTS network scenario. Additionally, the session establishment delay is negligibly affected by modifying the WiMAX channel rates. The network links have a slight impact on both delays since the processes that take place in each network entities such as P-CSCF, S-CSCF, I-CSCF and HSS, source and destination terminals, influence the processing and queuing delays. The processing and queuing delays are more affected by IMS service/processing rate, signalling arrival rate and by number of subscribers. The numerical results also indicate that the processing delay contributes the major delay for session establishment procedure. It can also be concluded that the lower channel rate of UMTS network has a major impact on the delay. Fortunately, all analysed delays are in the range of specified standard.

The work has been extended by investigating the emerging femtocell network, particularly on mobility functionality. The improvements have been figure out on handover decision strategy since hundreds of Femto Access Points (FAPs) may be applied in a femtocell network. We determined three types of handovers i.e., *hand-in, hand-out*, and *inter-FAP* handovers, additionally, the horizontal and vertical handovers have been taken into account as well. We brought the utilisation of LTE-based signalling procedure to provide the most efficient procedure for hand-in, hand-out, and inter-FAP handovers. Some new signalling messages have been introduced and proposed.

The improvement of handover decision policy on femtocell network is achieved by implementing a new metric of handover based on the prediction of user's movements. This new metric is used simultaneously with the existing metrics such as CINR, RSSI, coverage, and QoS. Accordingly, the proactive handover, reactive handover, and call admission control mechanism have been examined to obtain the most efficient strategy to trigger the handover process. Our simulation results showed that the reactive handover has better performance in mitigating the unnecessary handover in femtocell network.

Finally, the *Next Generation Wireless Network* (NGWN) architecture design has been proposed by introducing the all-IP connection to integrate the IMS core network with the femtocell network. The proposed design included the new approach of attach procedure, the mechanism how the *Femto User Equipment* (FUE) can be attached into the FAP, and consecutively register into IMS core network as IMS client. In addition, the SIP registration procedure in IMS is described and analysed in order to show the completed signalling flows in the integrated system. Five stages procedure has been proposed for the connection establishment in the integrated system, i.e., FAP acquisition, F-UE attach, SIP registration, session establishment and media transfer.

We consider our work on integrated performance of IMS and femtocell network as a milestone along this direction, and many research and technological development problems need to be addressed in the future. The proposed movement prediction as a new metric in handover decision policy seems quite promising. The movement prediction results enhanced the decision policy of handover to be more effective. Nevertheless, further work on how to integrate the new metric in to handover procedure of LTE-based femtocell network and how the PHY/MAC can be cooperated in term of this metric need to be performed. It is also worth to study the movement prediction when implemented in the inter-RAT handover.

Moreover, once the target BS can be predicted, so the strategy for handover can be enhanced. We proposed to implement the reactive as the handover strategy since it is the most efficient strategy to prevent the unnecessary handover. The future work may include the proactive handover and call admission mechanism for particular circumstances, also the deep investigation on impact of those strategies with the QoS.

For the further works we also suggest exploring and exploiting the efficiency of cellular-based integration of IMS - femtocell network, and *Unlicensed Mobile Access* (UMA) based integration. The work on simulation may corroborate the proposed mechanism and solution. Additionally, it is also important to find the most optimise network entry procedure. The embedded LTE attach and SIP registration into single entry procedure by cross-layer mechanism is turned into our consideration.

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1. **Ulvan, M., (50%)**, Ulvan, A., Bestak, R., "Interworking of IMS and Femtocell Network", has been accepted to be published in International Journal of Advancements in Computing Technology (IJACT), spring volume, 2013.
2. Ulvan, A., **Ulvan, M. (33%)**, Bestak, R.,"Handover Procedure and Decision Strategy in LTE-based Femtocell Network", in Telecommunication Systems Journal, Online First™, 9 August 2011, DOI: 10.1007/s11235-011-9587-0.

Publication included in WoS

3. **Ulvan, M. (50%)** - Bestak, R.: Analysis of Session Establishment Signaling Delay in IP Multimedia Subsystem. In *Wireless and Mobile Networking*. Berlin: Springer, 2009, p. 44-55. ISBN 978-3-642-03840-2.
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1. Telecommunication Journal (http://www.springer.com/business+%26+management/business+information+systems/journal/11235)

   - since 2008, 4 reviews .
2. International Journal of Advancements in Computing Technology (IJACT) (http://www.aicit.org/ijact/home/index.html)

   - since 2011, 2 reviews .
3. IEEE International Journal on Selected Areas in Communication (IEEE-JSAC) (http://www.jsac.ucsd.edu/)

   - since 2011, 1 review.
4. International Conference on Software, Telecommunication and Computer Networks (SoftCom) (http://marjan.fesb.hr/SoftCOM/2011/ and,http://marjan.fesb.hr/SoftCOM/2012/)

   - since 2011, 2 reviews.
5. International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UBICOMM) (http://www.iaria.org/conferences/UBICOMM.html)

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Involved grants and research projects:

1. IGS grant – CTU0921113, 2009.

   – Applicant of the grand project Ing. Melvi Ulvan.

2. SGS grant – SGS10/274/OHK3/3T/13, 2010-2012.

   – Applicant of the grand project Ing. Robert Bestak, Ph.D.

3. FRVS grant – FRV 211G1, 2009.

   – Applicant of the grand project Ing. Bc. Ladislav Chmela.

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SUMMARY

The Internet Protocol Multimedia Subsystem (IMS) is a new framework specified for 3G mobile networks, for providing Internet Protocol (IP) telecommunication services and features. The IMS functionality is designed to work on various wireless access technologies and in all network coverage such as macrocell, microcell, and particularly femtocell. A femtocell is a small cellular base station designed for use in residential or small business environments. It allows service providers to extend service coverage inside of our home, especially where access is limited or unavailable. The increasing demand for mobile traffic due to the large nomadic population and the availability of IMS applications has motivated the development of 4G networks. Macrocells are characteristically good at providing area coverage for 4G, but are not effective in providing high data rates per area due to their typically large coverage. For this reason, femtocell is take place. As an emerging access device, femtocell is widely developed. There are many technical studies exposing its benefits, however there only very few report portraying the integration of femtocell and IMS. The aim of this research is to determine and design the best suitable mechanism to integrate the IMS core network with femtocell network. In technical point of view, the thesis is composed of 3 parts. The first part is focused on the enhancement of SIP signalling mechanism and optimization of SIP signalling procedure on IMS' session establishment process. The structure of session establishment signalling process is enhanced. The performance evaluation methods of session establishment signalling by Session Initiation Delay (SID) is introduced and conducted at: IMS' entities (i.e., S-CSCF, P-CSCF, I-CSCF, and HSS); during the transmission of signal messages; and when the SIP messages are in network queues. The evaluation are deployed in several end-to-end wireless link scenarios i.e., UMTS to UMTS, WiMAX to WiMAX, UMTS to WiMAX and vice versa. The comprehensive analysis is done since it included the analysis of processing, transmission, and queuing delays.

The second part or the thesis included the investigation on one of the mobility functionality of femtocell network, i.e., handover procedure. The 3GPP LTE based handover procedure is considered. Three scenarios are studied: hand-in, hand-out and inter-FAP. The handover procedure and the signalling flows have also been analysed. Since plenty of target FAPs were involved in the hand-in process, it is a challenge to make a selection of the target FAP. The mobility prediction mechanism is proposed to cope with this issue. This scheme can be used to predict the heading position of the UE and then estimate the target FAP to which the UE may be connected. This part also comprised the proposal of E-UTRAN architecture enhancement as well as the modification of communication procedure among EPC, MME, SGW and FGW, in order to have a better procedure when deploying the femtocell into the system.

The last part of this thesis conducted the deployment of IMS service in femtocell environment. A feasible network integration designs called the SIP/IMS-based

integration with all-IP connectivity is proposed as a new design for the technology framework of the 4G wireless technology called the Next Generation Wireless Network (NGWN). The work included the development of a test-bed of the proposed design. In addition, the effective and efficient IMS Session Initiation Protocol (SIP) signalling when it works on femtocell environment is investigated. The enhancement of SIP signalling mechanism and optimization of SIP signalling procedure in femtocells environment network are conducted. The performance of the proposed system is analysed and examined by mean of simulation and test-bed experimental measurements. The test-bed, represented the proposed integration design, is composed of two IMS'clients which are registered separately into IMS core network through the FAPs. Network entry procedure of integrated LTE-based femtocell and IMS networks is also investigated. The attach procedure in 3GPP LTE-based technology and the SIP registration procedure in IMS are enhanced and modified in order to acquire the most effective network entry process. Finally, a new network entry procedure is introduced for the connection establishment in the integrated system.

RÉSUMÉ

V rámci mobilních sítí, ale i pevných sítí, se pro nasazování služeb využívajících na síťové vrstvě protokolu IP, s výhodou používá technologie IMS (*Internet Protocol Multimedia Subsystem*). Její výhodou je možnost relativně rychlé a za přijatelných finančních podmínek implementovat nové služby. V oblasti mobilních sítí, technologie IMS podporuje různé systémy jakož i různé velikosti oblasti pokrytí, od makro buněk přes mikro buňky až po nejmenší femto buňky. Makro buňky či mikro buňky jsou obecně vhodné pro venkovní pokrytí a služby vyžadující malé přenosové rychlosti. Nicméně, již se nehodí k pokrývání vnitřních prostor a pro služby s vysokými nároky na přenosové rychlosti. K těmto účelům je výhodnější využít femto buňky. Přístupové body femto buněk (FAPs, *Femtocell Access Points*) jsou *de facto* základnové stanice v miniaturizované podobě, které slouží k vykrytí vnitřních prostor budov (např. byty, kanceláře, obchodní centra, atd.), kde je pokrytí základnovými stanicemi makro / mikro buněk velmi špatné či dokonce vůbec žádné. Většina výzkumu okolo femto buněk se v současnosti především zabývá otázkami, jako jsou správa rádiových prostředků nebo připojení základnových stanic FAP k páteřní síti operátora. Nicméně, velmi málo studií a prací se zabývá otázkami integrace femto buněk v rámci technologie IMS. Tato disertační práce je zaměřena na problematiku signalizačních procedur při nasazovaní femto buněk do prostředí IMS.

Prvá část disertační práce je věnována protokolu SIP (Session Initiation Protocol) jakožto základního signalizačního protokolu v technologii IMS. Je zde analyzováno použití protokolu SIP a jeho optimalizace v prostředí femto buněk. Účinnost navrženého řešení v mobilních sítích UMTS a WiMAX je analyzováno jednak matematickým popisem a dále pomocí simulací a experimentálními měřeními.

V další části se práce věnuje problematice předávání spojení v sítích LTE, mezi makro a femto buňkou, femto a makro buňkou a mezi femto buňkami navzájem. Je detailně analyzována samotná procedura, jakož i výměna signalizačních zpráv při těchto procedurách. S ohledem na velké množství základnových stanic FAPs, jejich omezeným pokrytím a v důsledku pohyb uživatelů, setrvává uživatel ve femto buňce relativně krátkou dobu. K odhadnutí cílové základnové stanice FAP, ke které by měl být uživatel optimálně přepojen je využita predikce pohybu uživatele. Při znalosti pravděpodobné budoucí pozice terminálu, je možné odhadnout, na kterou základnovou stanici FAP má být spojení přepojeno. Tímto způsobem je možné omezit nežádoucí předávání spojení na jiné základnové stanice FAPs.

Poslední část disertační práce je věnována signalizační proceduře přístupu mobilních terminálů k základnovým stanicím FAP v sítích LTE. Na základě analýzy současného řešení je navrženo vylepšení stávajícího mechanismu pro připojení terminálu do sítě. Navržené řešení a jeho účinnost je ověřeno pomocí simulací a praktickým měřením prostřednictvím vytvořené testovací platformy.

BIOGRAPHY

Melvi Ulvan received the B.Eng degree in electrical engineering in 1997 from The University of North Sumatra, Indonesia, and M.Eng in Telecommunication Information System from Bandung Institute of Technology, Indonesia in 2002. In 2000-2006 periods she worked as a Lecturer at Department of Electrical Engineering, The University of Lampung, Indonesia. She is currently studying Ph.D. degree in Telecommunication Engineering at Czech Technical University in Prague, Czech Republic. She is also working as a researcher at wireless networks research group department of telecommunication engineering, CTU in Prague. Her research interests include Mobile IP, IP Multimedia Subsystem (IMS), and femtocell networks. She involved in several projects within the university and at CTU R&D Centre.